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Energy-Efficient Inter-Domain Routing Protocol for MANETs

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Abstract

In the last seven years, the focus of researchers in ad hoc networks field has shifted to inter-domain routing. Researchers used several methods to enhance the efficiency of routing between different mobile ad hoc networks (MANETs). These routing methods were based on clustering techniques, virtual coordinates, Ant Colony Optimization., etc. Inter-domain routing in MANETs relies on gateways. When a packet is sent from a source to a destination, it follows a route of internal and external connected gateways in different domains and as the MANETs are mobile (both individual nodes within a domain as well as whole domains relative to each other), the topology of the whole network composed of different domains can change in an intermittent way. Therefore, gateways belonging to different MANETs must know each other to be reconnected. In this paper we introduce our inter-domain routing proposal based on bees' communication to handle a dynamic topology in inter-Ad Hoc networks. The goal is to design an energy efficient inter-domain routing protocol for MANETs with low overhead.

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1. Introduction

Mobile Ad Hoc Networks (MANETs) are one field of emerging networks in the twenty first century. They are a kind of network that does not need any fixed infrastructure or central administration to be deployed. Most of research concerning routing in ad hoc networks focused on routing in a single domain. Seven years ago, at the end of 2007, a routing protocol called IDRM (Inter-Domain Routing protocol for MANETs) was developed by Crowcroft¹ et al. An inter-domain routing protocol can enable end-to-end communication across a set of heterogeneous mobile ad hoc networks operated by different organizations such as a navy force, medical crews, aircraft group, underwater

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crews, and police or fire-fighter forces. Each one of these ad hoc network domains are mobile, may use different transmission technologies and deploy different intra-domain routing protocols (such as AODV, OLSR, DSR, DYMO, etc.). The communication is achieved by routing packets between gateways belonging to each MANET. These gateways are used to route packets from one domain to another until the packet reaches its destination. As the MANETs are mobile and the battery capacity of the nodes is limited, the topology of the whole network can change in an intermittent way caused by split/merge of one or more domain(s) or by the arrival of another new domain to join the whole network. When there is a split or merge of a MANET to one or more sub-MANETs^{1,2}, the gateways belonging to different domains must know each other to be reconnected. In this case the routing table is maintained by sending periodic beacons between gateways during an interval of time to maintain a coherent state of the whole network. But this method generates an important overhead. Since this original proposal, researchers suggested several methods (virtual coordinates based routing^{3,4}, clustering based routing⁵, Ants Colony Optimization based routing⁶) to enhance the inter-domain communication between several heterogeneous networks while conserving the basic scheme interconnecting several MANETs. Swarm intelligence is an inspiration from the behavior of insects' labor journey for the discoverer of food and the maintenance of the life of their communities. In this paper we introduce our proposal for an energy-efficient and low-overhead inter-domain routing protocol based on the use of bees' communication (using swarm intelligence) for the discovery of inter-domain ad hoc topology changes. The proposed inter-domain routing protocol will work according to the bees' foraging principle using waggle dance.

2. Related Works

Our proposed algorithm is based on swarm intelligence, and nature has served as an inspiration for the development of a number of routing protocols. The first routing algorithm related to the use of Ants' communication was ARA⁷ "Ant-Colony based Routing Algorithm". The core of the algorithm is described in "AntNet"⁸ and "ABC"⁹, two swarm intelligence routing protocols for fixed network. "AntHocNet"¹⁰ is a routing algorithm designed for MANETs and based on AntNet. AntHocNet is a hybrid routing protocol using both a reactive mode of operation (on-demand route discovery) and a proactive mode of operation (periodic route discovery). However, the routing overhead of AntHocNet is a disadvantageous factor¹¹. The swarm intelligence method based on Ant Colony Optimization was also used in the inter-domain routing for MANETs. "Falko Dressler and Mario Gerla"¹² proposed to enhance inter-domain routing in MANETs, based on virtual cord for routing between a set of MANETs, by applying the ACO mechanism of the AntHocNet protocol to handle topology change. The result of their work showed that the proposed combination is efficient and had marginal overhead by applying ACO mechanism. Bees' communication was first studied by Karl Von Frish in 1911¹³. He spent his professional life studying the comportment of bees and won a Nobel Prize for his research. The application of bees' communication in routing data packets so far has only been introduced and developed for routing in a single MANET. Mudassar Farooq et al. developed a protocol called BeeHive for fixed networks¹⁴. They claimed that the study of honey bees has revealed a remarkable sophistication of the communication capabilities as compared to ants. Their work on BeeHive demonstrated that it can be more energy-efficient than AntNet and deliver the same or better performance. BeeAdHoc¹⁵ is an application of this principle to routing within a single MANETs, proposed by the same researchers. BeeAdHoc uses fewer control packets as compared to AntNet and AntHocNet, which decreases the routing overhead, and distributes traffic to different paths proportional to their quality and capacity, which makes it an energy-efficient routing protocol. Based on early results, BeeAdHoc shows also that packet delay is lower.

3. Basic Inter-Domain Routing in MANETs

In Fig. 1. below, when a node "A1" from domain "A" has to communicate with another node "C2" in an external domain "C", it routes packets to an accessible gateway "AG2". "AG2" routes packets to the gateway "BG3" using an **inter-domain routing protocol**, afterwards packets are routed to "BG4" using an underlying intra-domain routing protocol and so until the packet reaches its destination "C2". The inter-domain routing protocol is proactive, and thus the external routing table of each domain to different domains is known by at least all gateways.

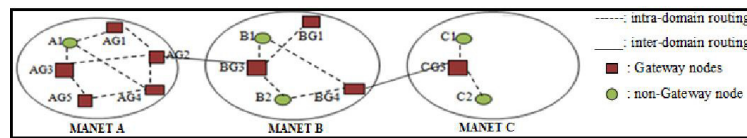


Fig. 1. Heterogeneous Interconnected MANETs.

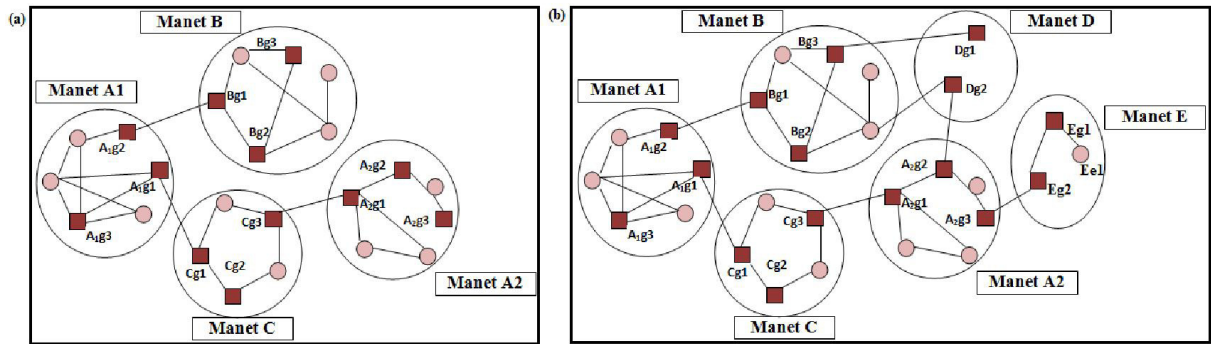


Fig. 2. (a) Split of domain "A" to domain "A1" and "A2"; (b) membership of MANETs "D" and "E".

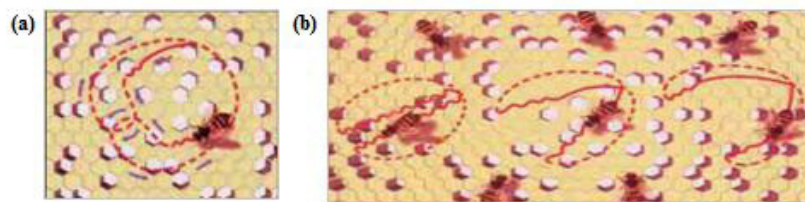
The challenge arising from mobility on the heterogeneous ad hoc network topology (see Fig. 2.) is the exchange of beacons (control messages) between gateways at the intra-domain level for being aware of split/merge events and at the inter-domain level when the neighborhood of certain MANETs change, such as when there is adhesion of a new MANETs. These beacons are required to maintain a coherent view of the whole network [2]. Note that relying on beaconing between gateways can generate an important overhead additional to the battery energy that will be lost.

4. Inter-Domain Routing for MANETs Based Bees' Communication

Bees are very organized, and communicate in a very complicated manner through dances. If a bee finds the food in a localized source, after a few time the other bees go to the same place for retrieving this food too. The way the bees share among them food' source is done by describing the location of this source using dance language. All information that other bees need to find food source are: its distance from the hive, its direction, and productivity: this one is encoded in the dance. The dancing process is performed in two dances, see Fig. 3.

4.1. Round Dance

The round dance is a round movement of the discoverer bee, it turn around itself in a quick rhythm of eight to ten tour/second then make a half round in the opposite sense. The other bees while observing this dance, know that source of nectar is near close to a radius of 50 meters

Fig. 3. (a) Round Dance. (b) Waggle Dance¹⁶

4.2. Waggle Dance

This type of dance is performed when food is located at a long distance from the hive, at this state and taking as reference the direction of the sun. The movement of this dance resembles to the number “eight”. In a typical dance, the bee moves in a straight line for a short distance, moving its body from side to side approximately 13 to 15 times a second and return after to the beginning point from which it start the dance tracing a half-circle. By varying the angle between the wagging run and an imaginary line running straight up and down, the bee conveys the direction of the food source. If a line is drawn which connects the food source and the hive, and another line which connects the hive and the spot on the horizon immediately below the sun, then the angle formed by the two is observed to be the same as that of the angle in the waggle dance.

4.3. Applying Bee Communication to Inter-Domain Ad Hoc Routing

Our idea will be inspired by the waggle dance since it will be applied to a large scale network of interconnected MANETs. The main work is to discover topology changes in inter-ad hoc domains reactively and to transmit data-packets proactively instead of relying on RouteRequest (RREQ) and RouteReply (RREP) messages only when there is data to transfer. A “discovered route” is propagated to the remote domains based on three metrics:

- End-to-end_Route_Delay:
It's the amount of time a packet consumes to travel a Route from a node in $MANET_i$ to another $MANET_j$, where $MANET_j$ is the MANET to discover when this one join the whole network.
- RouteLifeTime:
It's the total of the remaining battery in gateways forming a Route from a $MANET_i$ to another $MANET_j$ to be discovered.
- Available Bandwidth:
It's the average rate of data-transfer nodes in a route allow.

Route discovery and propagation will be based on “**DiscovererMANETs**” and “**ForwarderMANETs**”. Each gateway in the DiscovererMANETs and in the ForwarderMANETs have a CognitiveMap¹⁷ on which information about RouteQuality are stored and collected by mobile agents. When a new MANET comes joining the whole network, or a split domain comes in the transmission range of another neighbor domain, it announces itself by broadcasting “**HELLO**” messages.

DiscovererMANETs = { set of MANETs receiving “**HELLO**” message } and ForwarderMANETs = { set of MANETs from whom a discovered route is propagated }.

Discoverer _MANET contains a set of gateways receiving a “**HELLO**” message. **DiscovererGateways** propagate **RouteQuality** based on “**Delay, LifeTime, and AvailableBandwidth**” to remote domains. The following paragraphs outline how we use these metrics to determine high-quality paths among MANETs to solve the inter-domain routing task.

4.3.1. Delay

- A candidate gateway receiving a “**HELLO**” message creates a mobile agent **MA_D**. **MA_D** calculates the average delay in the MANET to which it belongs and stores the result in a variable **StatisticDelay**
- After that, **MA_D** is forwarded to domains connected to its home domain via the gateways to inform them of the average delay of its MANET. **The MA_D** communicating its delay to other domains contains both the **StatisticDelay** and **ID** of the MANET to which it belongs
- When gateways from a remote domain receive the **MA_D** from a neighbor MANET, **MA_D** adds the current **domainID** to the **struct** containing visited domains. It calculates the average delay of the current MANET, and updates **StatisticDelay** accordingly (i.e., adds this value to **StatisticDelay**).
- This operation is done for each **DiscovererMANET** and after that for each **ForwarderMANET** until the delay of all possible routes from a certain MANET to the discovered MANET is known.

- When applying this operation to scenario in figure 5, domain “A” will have average delay of all routes leading to the discovered MANET “E”

4.3.2. Route LifeTime

The RouteLifeTime is based on the sum of LifeTime of all MANETs forming a route. As we did for Delay, DiscovererGateways of DiscovererMANETs calculate LifeTime of domain to which they belong and transmit the result to the neighbor domains. Mobile agents are responsible of computing the LifeTime by taking values from physical devices, and are responsible of the transmission of the results to the neighbor domains.

4.3.3. Available Bandwidth

The average available bandwidth is collected by mobile agents from gateway devices and computed for each route from a discovered MANET to the remotes MANETs. After the three metrics are known in a certain $MANET_i$, and for each route from this $MANET_i$ to the discovered $MANET_e$, $MANET_i$ can choose routes on which it can transmit packets to the $MANET_e$ according to the lowest-cost path (lowest End-to-end_Route_Delay and highest RouteLifeTime and highest Bandwidth).

The three metrics discussed above are performed even there is no new joining domain. For that the inter-domain routing is enhanced based on low-cost path, and split and merge events are detected by mobile agents when performing delay computation and transmitting results between gateways. If at a certain time, mobile agents cannot reach a gateway previously reached for storing these RouteQuality metrics, at this time the corresponding MANETs are considered separated and a new domainID is determined and the discovery process is started. When RouteQuality of several routes is given to a $MANET_i$ it can choose which route takes to transmit its packets, see Fig. 5.

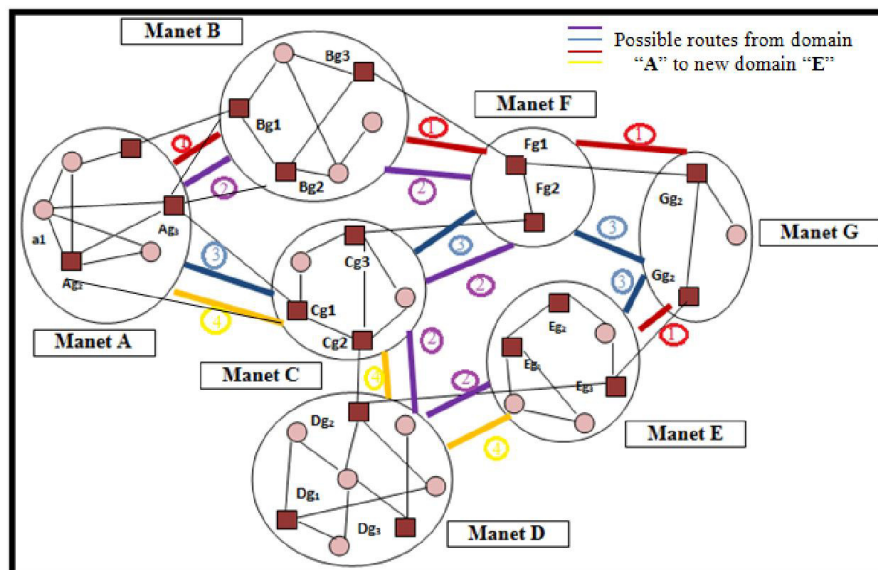


Fig. 4. Proposed Scenario to apply Bee Communication.

5. Conclusion

GOD has created a flawless (perfect) design, the bees. These insects made their own homes. For their nourishment and production of honey, there exist different kinds of bees in the hive (Worker bees, Queen bee, Male bees). The workers perform the entire task in the hive. The role of the queen bee is to ensure the hive' life continuity.

The only work made by males (drones) is to fertilize the queen. The main work of workers is to discover and gather food. In worker bees, there are discoverer bees and forager bees. The discoverer bees find food and tell its place by dancing language to the other bees. The forager bees follow the dance and collect food from the source.

In our work, we took inspiration from the propagation of Routes to food sources done by discoverer bees to the foragers bees and apply it to the topology discovery in Inter-Ad hoc Connected Networks. As the mobile agents are mobile codes that can migrate efficiently between nodes in mobile ad hoc networks (MANETs) using mobile agent migration mechanism, under the control of themselves, they can navigate through the underlying network and perform various tasks. Several works in the field of routing in mobile ad hoc networks either in intra-domain or inter-domain show the efficiency of using mobile agents. The overhead is minimized and the robustness of routing is enhanced, from where we use mobile agent migration mechanism to enhance our proposed scheme and making it energy-efficient through inspiration from Bee Communication. We used mobile agents to perform the computing and transmission of the RouteQuality. From a certain source “S” having Route Quality of several routes to reach a certain destination “D”, the source “S” can choose the low-cost route for transmitting its packets.

Future work will be to build the proposed solution for a large scale interconnected Mobile AdHoc Networks. We will use the network simulator ns-2.32 with the integration of the mobile agent framework for performing the computation made by each gateway, and to evaluate the throughput, packet delivery-ratio, energy-consumption, delay and overhead of the proposed approach.

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